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A STATISTICAL MODEL OF NUCLEAR SHELLS

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By comparing the binding energies, mechanical magnetic and quadrupole moments of nuclei, and other data, a number of authors (Nordheim, Feenberg, Goeppert-Mayer, M. A. Levitskaya, S. A. Shchukarev, and A. P. Znoyko) have concluded that nucleons in groups of

$$2,\ 8,\ 10,\ 20,\ 50,\ 82,\ 126 \qquad (1)$$

must form several closed nuclear layers or shells, similar to the electron shells in atoms of the inert gases.

A majority of the authors have decided on the following arrangement of the shells:

$$(1s)^2(2p)^6(2s)^2(3d)^{10}\ldots, \qquad (2)$$

which corresponds to the nuclei of He^4, O^{16}, Ne^{20}, Ca^{40}, etc. Elsasser's attempt in 1934 to determine theoretically the order of nuclear levels with the help of a model of a rectangular potential shell, leading to the series

$$1s,\ 2p,\ 3d,\ 2s,\ 4f,\ 3p,\ 5g,\ldots, \qquad (3)$$

is well known. In this series, however, the levels 3d and 2s must be interchanged even in the case of light nuclei. To obtain closed configurations containing 50, 82, and 126 particles in the case of heavy nuclei, the 2s, 3p, 4d, and other levels must be shifted forward with an increase of N and Z.

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We traced the formation of nuclear shells with the help of Thomas-Fermi statistics, which in the atomic case correctly gives the number of electrons which fill the s-, p-, and d-shells.

Integration of the equations obtained by this method produced the following equation:

$$N_e = Z_e = 1/12(2\ell+1)^3, \quad (\ell = 0, 1, 2, \ldots.) \qquad (4)$$

from which the following table was drawn up for the number of nucleons filling the s-, p-, d-shells; the corresponding numbers for the electron shells are included for comparison:

Level		According to (4)	Closest Higher Integer	For Electrons
0	s	0.08	1	1
1	p	2.25	3	5
2	d	10.42	11	21
3	f	28.58	29	58
4	g	60.75	61	--
5	h	110.92	111	--

From this table and formulas derived for the increase in the number of nucleons with respect to the azimuthal quantum number ℓ, the following sequence was obtained for filling the levels:

$$\begin{array}{lll} 2\ (s)^2 & \text{K-shell,} & \\ 10\ (1s)^2(2p)^6(2s)^2 & \text{K+ L-shell,} & (5) \\ 28\ (1s)^2(2p)^6(2s)^2(3d)^{10}(3p)^6(3s)^2 & \text{K+L+M-shell.} & \end{array}$$

The number of nucleons forming closed shells, therefore, is equal to

$$2,\ 10,\ 28,\ 60,\ 110. \qquad (6)$$

The sequence of levels and shells, as shown by (5), suggests the structure of electron shells, differing from it only in the reverse order of the levels in each shell and in the strict order in filling the shells, since each successive shell begins to be filled only after all preceding shells are filled. The last difference is probably due to the fact that attractive forces for the most part act between nucleons, in contrast to the repulsive forces between electrons.

In conclusion, we note that since arrangement (5) was obtained by a statistical method, it is not possible to establish the filling sequence for a large number of nucleons because the formulas used to obtain (5) are averaging formulas which do not take into consideration the individual characteristics of nuclei. Therefore, although the relative error would decrease for large A's, the absolute error could exceed tenths of units. In addition, the simplest law of nuclear forces was used in the discussion, and thus no consideration was given to their well-known spin, noncentral, and exchange effects.

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